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ANALYTICAL REFERENCE SERVICE TRAINING PROGRAM. WATER RADIOACTIVITY, NUMBER 3, OCTOBER 1963

Robert A. Taft Sanitary Engineering Center
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Report

WATER RADIOACTIVITY NO. 3

A Study Conducted by the
Analytical Reference Service
TRAINING PROGRAM
for the
Division of Radiological Health

Public Health Service
Bureau of State Services

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio
1963

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i. 62

ANALYTICAL REFERENCE SERVICE

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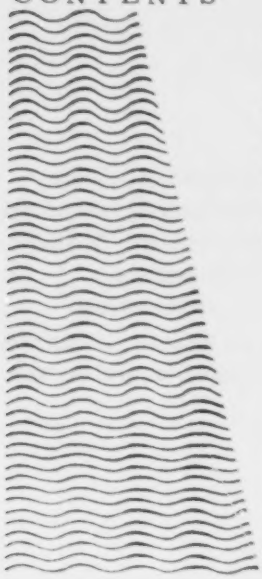
CONTENTS



FOREWORD

COMPLETED REPORTS

PARTICIPANTS IN THIS STUDY

INTRODUCTION

Purpose of Radiological Studies
Background of Studies

Objectives of this Study

a Analysis Scheme
b Sample Preparation

THE TWO-PART STUDY

A Gross Analysis

Reported Data
Discussion of Factors Affecting Gross Beta Counting Data
Summary of Results
Discussion

B Strontium-90 Analysis

Reported Data
Discussion of Factors Affecting Strontium-90 Counting Data
Summary of Results
Discussion

STATISTICS

Glossary of Statistical Terms
Probability Explanation

REFERENCES

ANALYTICAL REFERENCE SERVICE MEMBERSHIP

FOREWORD

The Analytical Reference Service is conducted by the Robert A. Taft Sanitary Engineering Center to provide a means of evaluating laboratory methods in the field of environmental sciences and engineering. Membership includes federal, state, and municipal agencies, industries, universities, consulting firms, and foreign agencies. Cooperative studies by member organizations, through analysis of identical samples of environmental media and critical review of methodology, provide the mechanism for:

Statistical evaluation of procedures, including precision and accuracy.

Comparison of analytical procedures and results between laboratories having similar responsibilities.

Exchange of information regarding method weaknesses.

Improvement of existing methods or development of newer, more accurate methods to replace current procedures.

Development and evaluation of entirely new methodology for the determination of new pollutional components, such as pesticides, herbicides, antimony, cadmium, boron, selenium, phenol, and trace air pollution contaminants.

Initially directed toward examination of water, the studies have been broadened to include other media. Samples are designed and prepared to contain measured amounts of selected constituents. Decisions as to qualitative makeup are made by the staff of ARS, the membership, and consultants. Notice of a study is forwarded to each member with information regarding the qualitative makeup of the sample and special details regarding its handling.

A portion of the sample is shipped to each member who indicates a desire to participate in the study. Accompanying each sample are data forms which provide space for reporting numerical analytical values and a narrative critique of the procedures used. The agencies are urged to comment on the methods, difficulties, modifications, sources of error, and other factors.

The results and comments of each study are compiled, as in the accompanying report. Experience indicates that a repeat study produces a sizeable increase in the number of participants. The first study designed to evaluate analytical methodology for the detection and measurement of radioactivity in water was completed in 1959, with 25 participants. Forty-one agencies participated in the 1961 study, while 54 cooperated in this study.

A report is now being prepared for the recent study conducted to evaluate three popular surfactant methods. A study designed to survey methods in use for counting and identifying plankton in freshwater is being completed. Two new studies are in the design stage: Particulate Material in Air and a repeat Biochemical-Chemical Oxygen Demand in Water type study.

The selection of studies is guided by answers to questionnaires distributed to member agencies to poll their interests. Results of this poll continue to serve as a useful aid in planning future studies.

Membership now consists of 170 agencies of diversified interests, with foreign interest increasing rapidly. The assistance and experience that agencies from other countries can bring to this program are invaluable to the entire membership.

H. P. Kramer
Director, Training Program

STUDIES ON WHICH REPORTS HAVE BEEN COMPLETED

Water-Minerals	Calcium, magnesium, hardness, sulfate, chloride, alkalinity, nitrite, nitrate, sodium, and potassium. Studies completed in 1956, 1958, and 1961.
Water-Metals	Lead, copper, cadmium, aluminum, chromium, iron, manganese, and zinc. Studies completed in 1957 and 1962.
Water-Fluoride	Fluoride in the presence and absence of interferences, with and without distillation using a specified procedure. Studies completed in 1958 and 1961.
Water-Radioactivity	Gross beta and gamma activity. Studies completed in 1959 and 1961.
Water-Surfactant	Surfactant in various waters. Study completed in 1959. Report on second study to be distributed in the near future.
Water-Oxygen-Demand	Biochemical oxygen demand and chemical oxygen demand. Study completed in 1960.
Water Trace-Elements	Arsenic, boron, selenium, and beryllium. Study completed in 1962.
Air-Inorganics	Chloride, sulfate, fluoride, and nitrate in aqueous solution and on glass fiber hi-vol filter mats. Study completed in 1958.
Air-Lead	Filter paper tape impregnated with lead. Study completed in 1961.
Air Sulfur-Dioxide	Determination of sulfur dioxide in air using a specified method. Study completed in 1963.
Milk DDT-Residue	DDT in milk. Study completed in 1962.

PARTICIPANTS IN THIS STUDY

Associated Universities Incorporated, Brookhaven National Laboratory
Battelle Memorial Institute, Columbus, Ohio
California Department of Public Health, Berkeley
California Disaster Office, Sacramento
City of Durham Department of Water Resources
City of Philadelphia Water Department
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Combustion Engineering Incorporated, Windsor, Connecticut
Connecticut State Department of Health, Hartford
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Kentucky State Department of Health
Los Angeles Department of Water and Power
Mare Island Naval Shipyard, Vallejo, California
Massachusetts Department of Public Health, Amherst
Metropolitan Water District of Southern California, La Verne
Metropolitan Water, Sewerage, and Drainage Board, Sydney, Australia
Michigan Water Resources Commission, Lansing
Minnesota State Department of Health, Minneapolis
Mississippi State Board of Health, Jackson
Missouri Department of Public Health and Welfare, Jefferson City
Montana State Board of Health, Helena
National Bureau of Standards, Washington, D. C.
New Jersey State Department of Health, Trenton
New York State Department of Health, Albany
Northeastern Radiological Health Laboratory, Winchester, Massachusetts
Nuclear Science and Engineering Corporation, Pittsburgh, Pennsylvania
Omaha Metropolitan Utilities District
Pennsylvania Department of Health, Harrisburg
Pearl Harbor Naval Shipyard, Industrial Hygiene Division
Pensacola Jr. College, Pensacola, Florida

Philadelphia Suburban Water Company
PHS Off-Site Radiological Safety Program, Las Vegas
Portsmouth Naval Shipyard, Portsmouth, New Hampshire
Public Health Laboratories, St. Louis, Missouri
Reynolds Electrical and Engineering Company, Inc. Mercury, Nevada
Rhode Island State Department of Health, Providence
Rutgers - The State University, New Brunswick, New Jersey
Sandia Corporation, Sandia Base, Albuquerque, New Mexico
South Carolina State Board of Health, Columbia
South District Filtration Plant, Chicago, Illinois
Southeastern Radiological Health Laboratory, Montgomery, Alabama
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2794th USAF Dispensary - Class B, Kelly Air Force Base, Texas
U.S. Geological Survey, Denver, Colorado
Utah State Department of Health, Salt Lake City
Vermont State Department of Health, Industrial Hygiene Division, Barre
Wisconsin State Board of Health, Madison

WATER RADIOACTIVITY NO. 3

PURPOSE OF RADIOACTIVITY STUDIES

Government agencies are increasingly concerned with radioactivity concentrations in the environment (air, food, milk, water, and vegetation). In environmental surveillance programs, water samples are routinely measured for gross activity and, where indicated, for the activity of specific radionuclides. Measurement of radioactivity is complicated by such factors as the calibration standard used, sample preparation, and self-absorption. To examine these complicating factors, the Analytical Reference Service undertook a series of studies to evaluate methods for the determination of radioactivity levels in environmental samples, to stimulate interest in improvement of laboratory performance, and to point out errors in the use of analytical procedures.

The first study of the series, Water Radioactivity No. 1 (1959), was a sample containing thallium-204 (a pure beta-emitting radionuclide) in tap water. It was designed to identify the factors affecting gross beta determinations, rather than to establish a method. The second study, Water Radioactivity No. 2 (1961), was a sample containing cesium-137 (a beta-gamma emitting radionuclide) in tap water. This study was designed to evaluate the factors which affected the results of the first study. A method of analysis was specified. The data obtained in the two studies[1] support the following conclusions:

1 Approximately half of the series participants determined gross radioactivity within 10-15 percent of the true activity of the sample.

2 The majority of the reported values were significantly below the true activity of the sample, suggesting that the true radioactivity of environmental samples was higher than was being reported.

3 Of the available standards for instrument calibration, Tl^{204} or Cs^{137} appears to be satisfactory for beta counting, and Cs^{137} appears to be satisfactory as a gamma standard. Other standards tend adversely to affect the reliability of the results.

4 In counting water samples for gross beta radioactivity a solids thickness of 20 mg/sq cm or less is recommended.

5 The internal proportional counter is the instrument of choice for the counting of gross beta activity, although the end-window counter may yield satisfactory results if geometry factors are rigidly controlled.

6 Of the 21 agencies who participated in the first two studies, mean recoveries of 75.7 and 92.5 percent, respectively, of the amount added were noted, indicating a marked improvement in the second study.

7 Further research and evaluation are needed to develop adequate standard procedures for the determination of gross beta and gamma radioactivity of environmental samples.

In view of these conclusions and of the improvement noted in the second study, it was decided to expand the series. A sample was designed which not only could be analyzed for gross beta activity (Sr^{90} - Y^{90}), but to include also analysis of a specific radionuclide (strontium-90).

OBJECTIVES OF THIS STUDY

In conformance with the design of the study, the objectives fall into two categories. For the gross beta portion, they were to:

1 evaluate further the variables which appeared in the first two studies;

2 evaluate in detail the effects of calibration standards, i.e., to what extent self-absorption standards are used, and if so, how they are prepared.

For the strontium-90 portion of the study, the objectives were to evaluate the effect of:

1 method of concentration of strontium carrier,

2 method of strontium purification,

3 method of strontium storage during ingrowth,

4 yttrium-90 separation method,

5 instruments used,

6 standards used,

7 method of determination of strontium carrier yield, and

8 method of sample preparation for counting.

ANALYSIS SCHEME

For gross beta activity, four recommendations were made to the participating agencies:.

1 Use a sample volume of 500 ml.

2 Maintain evaporation temperature at less than boiling.

3 Store sample, before counting, in desiccator or drying oven.

4 Analyze in triplicate.

For strontium-90 activity, two recommendations were made:

1 Use a sample volume of 500 ml.

2 Analyze in triplicate.

Three radionuclides commonly used as standards for gross beta activity determinations are thallium-204, cesium-137, and strontium-90 yttrium-90 (in equilibrium). Since thallium-204 and cesium-137 were used in the first two studies, strontium-90 yttrium-90 was selected for the third sample. Its use as a gross beta standard has been recommended also by the American Society for Testing and Materials (Method D-1890-61T). And to simulate a natural water, the sample was made with tap water.

SAMPLE PREPARATION

The sample was prepared by adding 100 lambdas (microliters), accurately measured, of a Sr^{90} - Y^{90} standard solution to 400 liters of Cincinnati tap water. The Sr^{90} - Y^{90} solution was calibrated by the supplier at 2.73×10^4 disintegrations per second per milliliter.

Sufficient HCl was added to the mixing tank to lower the pH to about 5 and to prevent yttrium-90 losses through "plating out" on polyethylene after bottling. The sample was thoroughly mixed by magnetic stirring for two days.

Aliquots of the sample were sent to 54 participating agencies and to referee laboratories together with a report form requesting information concerning methods of sample preparation, counting techniques, etc. The form was set up in two parts for the separate reporting of gross beta and strontium-90 results. The data obtained comprise the basis for this report.

THE TWO-PART STUDY

A Gross Analysis

Concentrations of the aliquot samples reported by the referee laboratories are listed below. Note that the calculated value of activity added (186 pc/l* of Sr^{90} - Y^{90}) was not used in determining the mean value of activity added, because the calculated value does not take into account any activity originally present in the substrate tap water. ARS analysis of the substrate indicated that approximately 10 pc/l was present before the Sr^{90} - Y^{90} was added. It was decided to average referee results rather than to combine the calculated amount with the background present in the tap water.

	Gross beta (pc/l)	Sr^{90} (pc/l)
Calculated activity	186(1)	93 ± 4
Radiological Health Research Activities	215 ± 10(2)	87 ± 9
Oak Ridge National Laboratory	202 ± 9(3)	90 ± 6 92 ± 5
Average (activity added)	209 ± 7	90 ± 3

* 1 pc/l = 1 μμc/l. Experience has shown that it is more convenient to express radioactivity concentrations in picocuries rather than in microcuries per ml.

(1) Not used in average.

(2) Using simulated mixed-fission products as standard (Sr^{89} and Sr^{90} - Y^{90} in equilibrium).

(3) Using Sr^{90} - Y^{90} in equilibrium as standard.

Of interest is the comparison of results using the three standard radionuclides - Sr^{90} - Y^{90} (in equilibrium), Cs^{137}, and Tl^{204}. While ORNL used Sr^{90} - Y^{90} for its referee analysis, it also calculated the concentration of the sample using Cs^{137} and Tl^{204}. These results are summarized below:

	pc/l		
	Sr^{90}-Y^{90}	Cs^{137}	Tl^{204}
Recoveries of ORNL Referee Laboratory	202 ± 9	237 ± 10	222 ± 9

REPORTED DATA

Forty-eight of the 54 participating agencies returned results which are included in this report. Agency #6111 reported two results and these are assigned a double code - 6111a and 6111b. Four sets of data were rejected as outliers, as they were erratic for no discernible reason. These rejected values are circled on the probability curve found on page 19 and were not used in the calculation of the statistical data. The construction of the probability curve and the definition of statistical parameters used in this report are detailed under Glossary of Statistical Terms, page 38. The bar graph, page 20, permits visual evaluation of the overall performance of participants in the gross beta counting portion of this study. The data reported by the 48 agencies are summarized below:

No. of agencies reporting	48
No. of results	49
No. of replicates	148
Amount of radioactivity in sample (mean value)	209 pc/l
Amount recovered (mean value)	201 pc/l
Median	202 pc/l
Range	256 pc/l
50% range	±30 pc/l
No. within ± 10% of amount added	63
No. within ± 50% of amount added	144
Mean percent deviation from amount added	19%
Mean percent deviation within laboratories	3%
Standard deviation	50 pc/l

In Table I are summarized the factors affecting gross beta results, the type of counter used, choice of standard, choice of self-absorption standard (if used), and sample thickness. Table II details the results of each laboratory. The previous summaries are based on these reported data.

Table I. SUMMARY OF FACTORS AFFECTING GROSS BETA RESULTS

	No. of results	Radioactivity recovery (mean pc/l)
TYPE OF COUNTING INSTRUMENT*		
End window	18	177
Gas-flow end-window	15	177
GM end-window	3	176
Internal proportional	30	216
CHOICE OF STANDARD**		
Cesium-137	16	212
Strontium-90 Yttrium-90	14	185
Thallium-204	5	258
Potassium-40	3	158
Others	8	184
SELF-ABSORPTION STANDARD USED***		
Yes	31	208
No	16	180

* One laboratory did not report type of instrument.
** Three laboratories did not report standard used.
***Two laboratories did not answer.

	No. of results	Radioactivity recovery (mean pc/l)
NUCLIDE USED BY LABORATORIES EMPLOYING SELF-ABSORPTION STANDARDS*		
Cesium-137	12	216
Strontium-90 Yttrium-90	7	198
Thallium-204	4	263
Potassium-40	3	158
Others	4	184
SAMPLE THICKNESS**		
Less than or equal to 10 mg/cm^2	23	207
Between 10 and 20 mg/cm^2	8	198
Greater than 20 mg/cm^2	7	182

*One laboratory did not report nuclide used.
**One laboratory did not report sample thickness.

Table II. DATA AFFECTING GROSS BETA RESULTS

Lab. No.	Mean result pc/l	Beta calibration standard	Self-absorption st'd. used	Type of counter	Average solid thickness in mg/cm^2
7112	114	Cs^{137}	No	Internal proportional	16.2
5231	115	$Sr^{90} - Y^{90}$	No	Gas-flow end-window	8.6
8222	120	RaD&E	No	Gas-flow end-window	10.6
2116	129	Cs^{137}	Yes	Internal proportional	7.9
3416	131	$Sr^{90} - Y^{90}$	No	Internal proportional	---
3911	136	$Sr^{90} - Y^{90}$	No	Low background beta gas-flow end-window	10.0
6411	148	Cs^{137}	Yes	---	7.9
8812	152	Bi^{210}	Yes	Internal proportional	23.0
4711	154	Cs^{137}	Yes	Internal proportional	19.2
010	154	K^{40}	Yes	Gas-flow end-window	30.0
7622	159	---	No	Internal proportional	7.2
6314	159	K^{40}	Yes	Low background beta, Geiger Mueller	8.4

Lab. No.	Mean result pc/l	Beta calibration standard	Self-absorption st'd. used	Type of counter	Average solid thickness in mg/cm^2
05	160	Y^{90}	No	Low background beta, gas-flow end-window	6.4
4611	162	K^{40}	Yes	Low background beta, Geiger Mueller	30.1
1611	177	$Sr^{90} - Y^{90}$	Yes	Low background beta, gas-flow end-window	6.5
5733	184	Cl^{36}	Yes	Internal proportional	11.6
2811	189	$Sr^{90} - Y^{90}$	No	Low background beta, gas-flow end-window	7.0
5811	190	$Sr^{90} - Y^{90}$	Yes	Gas-flow end-window	37.8
6512	190	Cs^{137}	Yes	Internal proportional	6.3
3611	191	$Sr^{90} - Y^{90}$	Yes	Internal proportional	7.5
01	192	Energy Efficiency curve	Yes	Gas-flow end-window	32.6
2336	194	Sr^{90}-Y^{90}	No	Gas-flow end-window	7.0
5611	194	Cs^{137}	---	Internal proportional	5.6

Lab. No.	Mean result pc/l	Beta calibration standard	Self-absorption st'd. used	Type of counter	Average solid thickness in mg/cm^2
3316	198	$Sr^{90} - Y^{90}$	Yes	Low background beta, gas-flow end-window	4.2
7912	198	$Sr^{90} - Y^{90}$	Yes	Internal proportional	7.0
4321	204	Cs^{137}	Yes	Internal proportional	6.6
08	206	U_2^{234}	Yes	Geiger Mueller end-window	29.2
1811	210	Cs^{137}	Yes	Internal proportional	9.7
7422	210	Tl^{204}	Yes	Internal proportional	5.9
5311	214	Cs^{137}	No	Gas-flow end-window	7.0
5933	216	$Sr^{90} - Y^{90}$	Yes	Gas-flow end-window	6.4
2611	218	---	No	Internal proportional	9.2
7222	218	$Sr^{90} - Y^{90}$	Yes	Internal proportional	8.7
03	218	---	Yes	Internal proportional	7.0

Lab. No.	Mean result pc/l	Beta calibration standard	Self-absorption st'd. used	Type of counter	Average solid thickness in mg/cm^2
5711	218	$Sr^{90} - Y^{90}$	No	Internal proportional	7.7
04	220	RaD&E	No	Internal proportional	19.5
4933	220	$Sr^{90} - Y^{90}$	No	Low background beta, gas-flow end-window	38.1
6911	221	Cs^{137}	Yes	Internal proportional	1.8
1315	226	Cs^{137}	Yes	Internal proportional	14.5
3511	235	U_3O_8	No	Internal proportional	6.8
4523	240	Tl^{204}	No	Internal proportional	7.2
1311	259	Cs^{137}	Yes	Internal proportional	5.7

Lab. No.	Mean result pc/l	Beta calibration standard	Self-absorption st'd. used	Type of counter	Average solid thickness in mg/cm^2
2411	260	Cs^{137}	Yes	Internal proportional	3.8
8512	271	Tl^{204}	Yes	Internal proportional	7.3
3211	280	Cs^{137}	---	Internal proportional	15.2
8112	282	Tl^{204}	Yes	Gas-flow end-window	16.9
9713	288	Tl^{204}	Yes	Internal proportional	10.0
6111a	295	Cs^{137}	Yes	Internal proportional	5.1
6111b	298	Cs^{137}	Yes	Internal proportional	5.4

DISCUSSION OF FACTORS AFFECTING GROSS BETA COUNTING DATA

To reiterate, the counting of gross beta activity seems to have been affected by the:

1 Type of counting instrument

2 Choice of standard

   a Use of self-absorption standard

   b Radionuclide used in preparing the self-absorption standards.

3 Sample thickness

Type of Counting Instrument

From the results in Tables I and II, internal proportional counters appear to be more reliable than end-window counters for the determination of gross beta activity. However, examination of the end-window counting data in Table III reveals the reason for this appearance. They indicate that gas-flow end-window counters are as reliable as internal proportional counters for the determination of gross beta activity, provided a self-absorption series is used for determining counting efficiencies and sample thickness is held to about 10 mg/cm^2, when possible.

Table III. INSTRUMENTS USED

	No. of results	Mean pc/l
Gas-Flow End-Window	15	177
Used self-absorption standard	7	201
Sample thickness less than or equal to 10 mg/cm^2	4	216
Sample thickness greater than 10 mg/cm^2	3	182
Did not use self-absorption standard	8	161
Sample thickness less than or equal to 10 mg/cm^2	6	168
Sample thickness greater than 10 mg/cm^2	2	170
Geiger Mueller End-Window Counters		
Used self-absorption standard	3	178
Internal Proportional Counter*	30	216
Used self-absorption standards	20	225
Sample thickness less than or equal to 10 mg/cm^2	16	229
Sample thickness greater than 10 mg/cm^2	4	211
Did not use self-absorption standards	8	182
Sample thickness less than or equal to 10 mg/cm^2	6	214
Sample thickness greater than 10 mg/cm^2	2	167

*Two laboratories did not report whether or not they used self-absorption standards.

Choice of Standard

According to the results in Tables I and II, the two factors to be considered when selecting a calibration standard appear to be the radionuclide and preparation of a self-absorption standard curve.

While the data seem to indicate that either Cs^{137} or Sr^{90} - Y^{90} is a suitable standard for determining gross beta activity, the results are lower when the counting efficiency is not obtained from a self-absorption standard curve. All of the values reported in Table IV were obtained using efficiencies from self-absorption standards.

The average of 7 results for Sr^{90} - Y^{90} as a standard is 198 pc/l over a range of 177-218 pc/l. The average of 12 results using Cs^{137} as a standard is 216 pc/l over a range of 129-298 pc/l. The average of 4 results using a Tl^{204} standard is 263 pc/l over a range of 210-288 pc/l. Of further interest is a comparison of the instruments used by the laboratories which used the radionuclides mentioned above for self-absorption studies.

These data indicate also that choice of standard and use of a self-absorption curve have greater influence on gross beta results than does the choice of instrument.

Table IV. INSTRUMENTS USED BY LABORATORIES WITH VARIOUS SELF-ABSORPTION STANDARDS

	No. of participants	Mean recovery pc/l
Cesium-137		
Internal proportional counter	12	216
Strontium-90 Yttrium-90		
Internal proportional counter	3	202
Gas-flow end-window counter	$\frac{4}{7}$	195
Thallium-204		
Internal proportional counter	3	260
Gas-flow end-window counter	$\frac{1}{4}$	282
Others		
Internal proportional counter		
Bismuth-210	1	152
Chlorine-36	$\frac{1}{2}$	184
Gas-flow end-window counter		
Energy efficiency curve	1	192
Potassium-40	$\frac{1}{2}$	154
Geiger Mueller end-window counter		
UX_2^{234}	1	206
Potassium-40	$\frac{2}{3}$	160

Effect of Sample Thickness

The best results were obtained by agencies using a sample thickness of less than 10 mg/cm^2. The mean activity of 32 results from less than 10 mg/cm^2 was 209 pc/l. The mean activity for 8 results from 10 and 20 mg/cm^2 was 198 pc/l. The mean activity for 7 results from greater than 20 mg/cm^2 was 182 pc/l. These figures indicate a trend toward slightly lower values as sample thickness increases. A tabulation of results comparing sample thicknesses less than and greater than 10 mg/cm^2 is shown below:

	No. of results	Mean recovery pc/l
Less than or equal to 10 mg/cm^2	33	207
Greater than 10 mg/cm^2	15	190
(One lab. did not report sample thickness)		
Less than or equal to 10 mg/cm^2	33	207
Used self-absorption standard	21	217
Did not use self-absorption standard	11	189
Greater than 10 mg/cm^2	15	190
Used self-absorption standard	10	190
Did not use self-absorption standard	4	169
(Two laboratories did not report whether or not self-absorption standards were used)		

A review of these data again direct attention to a tendency for lower results if self-absorption standards are not used for the determination of counting efficiencies.

CONCLUSIONS

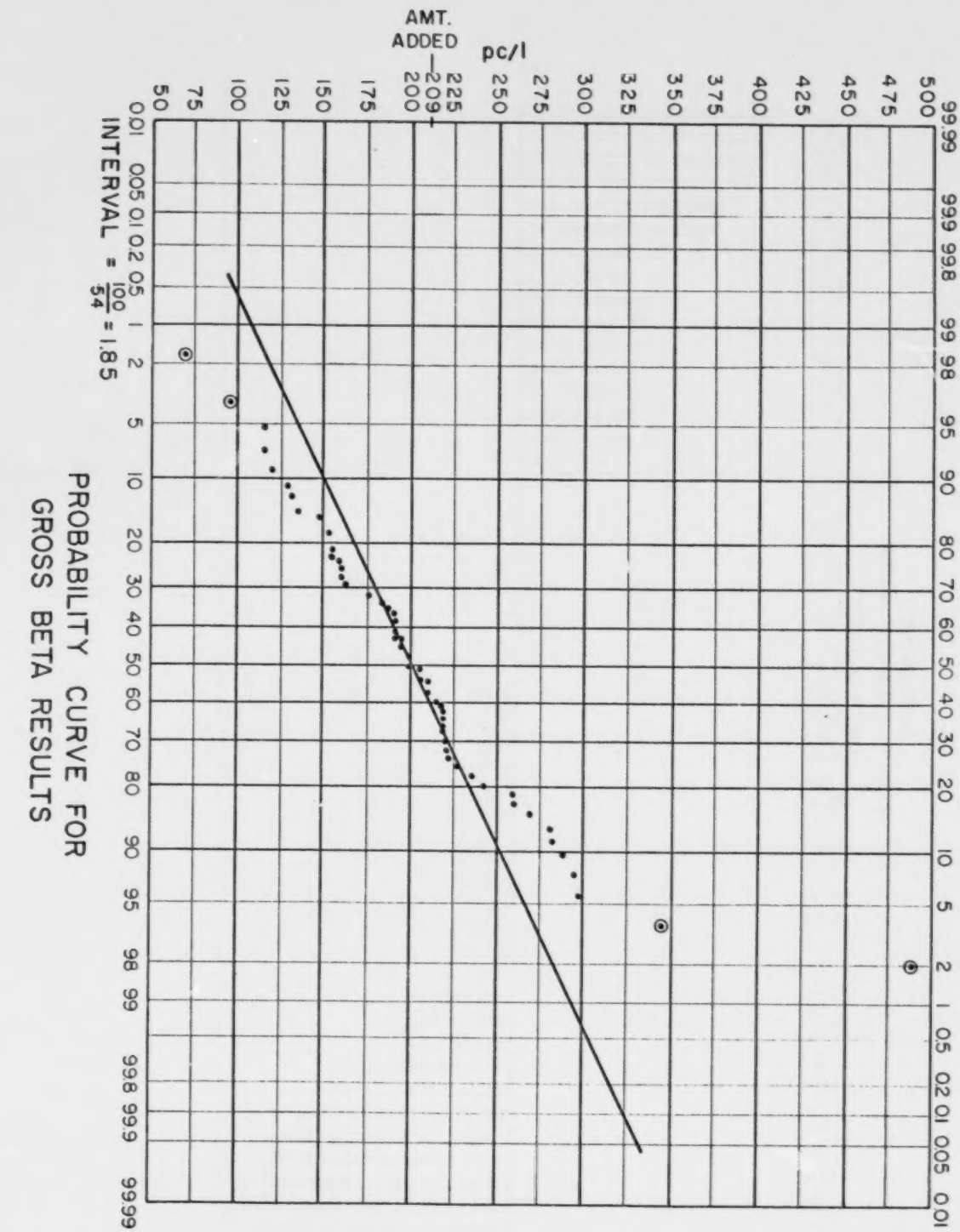
From the data submitted by 48 agencies for gross beta determinations on the environmental sample, Water Radioactivity No. 3 containing strontium-90 yttrium-90 (in equilibrium), the following conclusions were reached:

1 When counting efficiencies are obtained from self-absorption standards, both internal proportional and end-window counters are satisfactory instruments for gross beta radioactivity determinations.

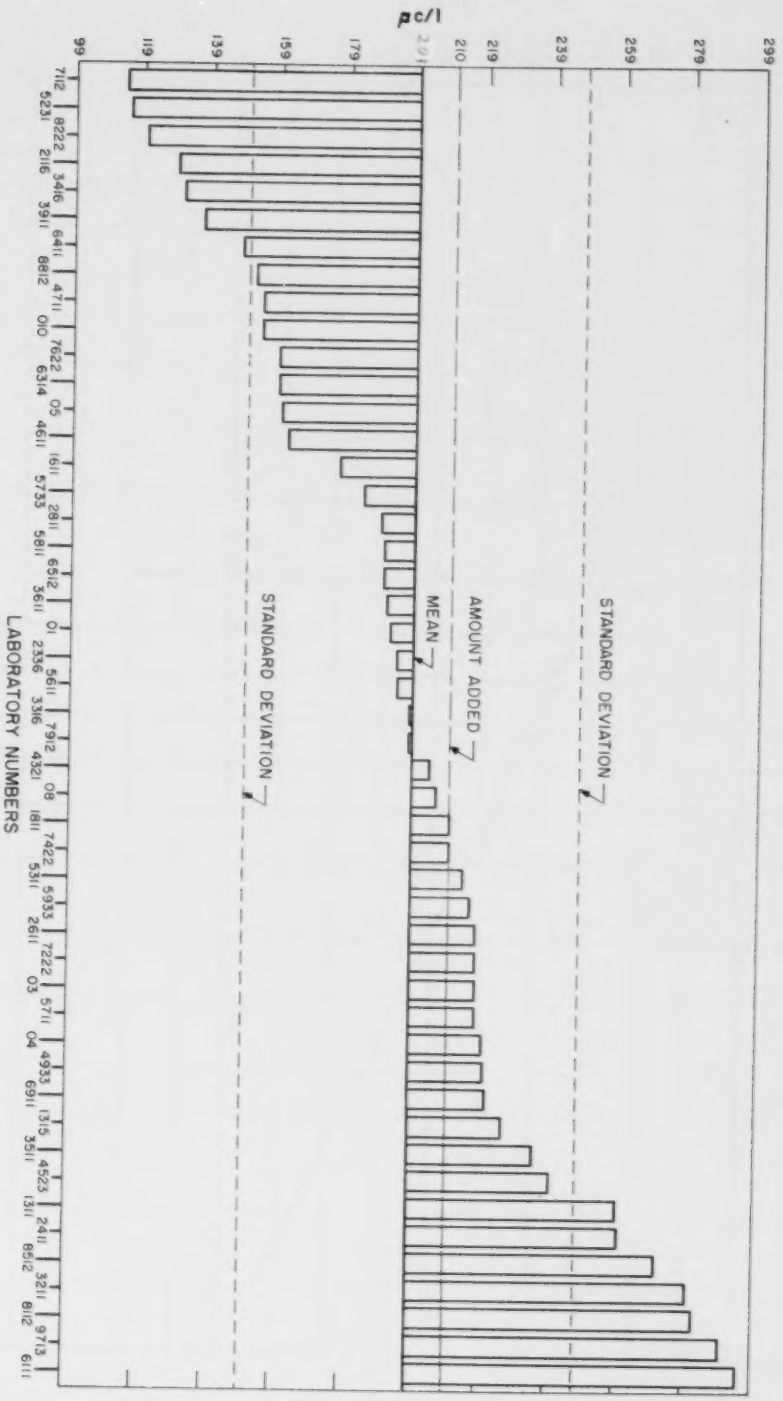
2 Both cesium-137 and strontium-90 yttrium-90 are satisfactory standards, provided they are used in the preparation of self-absorption standards. Although thallium-204 proved satisfactory as a gross beta standard in the first two studies in this series, subsequent problems encountered have discouraged its use as a standard.

3 In general, a sample thickness of less than 10 mg/cm^2, used in conjunction with a self-absorption standard curve for determining counting efficiency, produced the most reliable results.

In the first two studies in the series, gross beta determinations tended to yield low results. In this study, the mean recovery for 148 replicate results was 201 pc/l or essentially 100% recovery, since the mean value of radioactivity added, 209 pc/l, was estimated to have an error of $\pm$ 7 pc/l. This improvement is shown by the results which are not as heavily skewed toward the low side as were those in Studies Nos. 1 and 2. Of the 148 replicates, 86 were equal to or less than the added value of 209, and 64 were higher. This trend is encouraging from a public health viewpoint, as the two previous studies indicated that public health agencies were reporting results on the low side. As shown in the Tables, when self-absorption standards were prepared using Cs^{137} or Sr^{90} - Y^{90}, the results on an average were within 10 percent of the added value.



PROBABILITY CURVE FOR
GROSS BETA RESULTS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119
139
159
179
201
210
219
239
259
279
299
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MEAN
STANDARD DEVIATION
7112 8223 2116 3416 3911 6411 6812 4711 010 7622 6314 05 4611 161 5733 2811 5811 6512 361 01 2336 5611 3316 7912 4321 08 1811 7422 5311 5933 2611 7222 03 5711 04 4933 6911 1315 3511 4523 1311 2411 6512 3211 6812 9713 6111
LABORATORY NUMBERS
WATER - RADIOLOGICAL NO. 3
GROSS BETA

THE TWO-PART STUDY

B Strontium-90 Analysis

Concentrations of the aliquot samples reported by the referee laboratories are listed below:

	pc/liter
Calculated activity	93 ± 4
Radiological Health Research Activities	87 ± 9
Oak Ridge National Laboratory	90 ± 6 92 ± 5
Average (activity added)	90 ± 3

REPORTED DATA

Thirty-four agencies participated in this portion of the study and contributed 36 results. Agencies number 5933 and 8613 reported two results each and both were assigned double codes - 5933a and 5933b, 8613a and 8613b respectively. The probability curve, page 36, does not indicate a normal distribution. All results were included for statistical calculations although the 5 lowest values on the curve were not considered in other than the summary below and in Tables V and VI. The bar graph, page 37, presents a comprehensive picture of results for all participants. The data reported by the 34 agencies are summarized below:

No. of agencies reporting	34
No. of results	36
No. of replicates	99
Amount of radioactivity in sample (mean value)	90 ± 3 pc/l
Amount recovered (mean value of replicates)	74 pc/l
Median (of replicates)	84 pc/l
Range (of replicates)	107 pc/l

In Table V are summarized the factors affecting the strontium-90 results as to type of counter used, choice of standards, activity counted, yttrium-90 separation technique, storage of strontium during ingrowth, methods of strontium and yttrium yield determination, and method of preparing samples for counting.

Table V. SUMMARY OF FACTORS AFFECTING STRONTIUM-90 RESULTS

	No. of results	Radioactivity (mean pc/l)
TYPE OF COUNTING INSTRUMENT*		
Internal proportional	10	57
Gas-flow end-window	19	81
Geiger Mueller end-window	5	86
CHOICE OF STANDARD**		
Strontium-90 Yttrium-90 (in equilibrium)	10	78
Yttrium-90	11	89
Thallium-204	5	53
Cesium-137	2	77
Strontium-90	2	91
Others	3	63
ACTIVITY COUNTED		
Yttrium-90	23	73
Strontium-90	7	76
Strontium-90 Yttrium-90	6	75

* Two laboratories did not report.
** Three laboratories did not report.

	No. of results	Radioactivity (mean pc/l)
YTTRIUM-90 SEPARATION TECHNIQUE		
Solvent Extraction	12	57
1 Tributyl Phosphate (TBP)	8	43
2 Thenoyl Trifuloroacetone (TTA)	2	78
3 Di-2-ethylhexyl-o-phosphoric acid (HDEHP)	2	88
Precipitation	10	91
1 Hydroxide followed by oxalate	9	90
2 Hydroxide alone	1	100
Nitric Acid Extraction	1	99
STORAGE OF STRONTIUM DURING INGROWTH*		
As Solid	26	69
As Liquid	8	88
METHOD OF YTTRIUM YIELD DETERMINATION		
Assumed Yield by Solvent Extraction	13	60
Gravimetric	10	91

* Two laboratories did not report.

	No. of results	Radioactivity (mean pc/l)
METHOD OF PREPARING SAMPLE FOR COUNTING*		
Pouring	18	64
Filtration	12	87
Pipetting	3	70
Centrifuging Directly onto Planchet	1	88

* Two laboratories did not report.

Table VI presents a general summary of the separation, sample preparation, instrumentation, and calibration methods used by all the laboratories. A system of abbreviations are used to present the table in condensed form.

Strontium Concentration

- E - Evaporation
- O - Oxalate precipitation
- N - Nitrate precipitation
- C - Carbonate precipitation
- I - Ion exchange

Strontium Purification

- N - Nitrate precipitation
- F - Ferric hydroxide scavenge
- B - Barium chromate scavenge
- C - Carbonate precipitation
- O - Oxalate precipitation
- A - Acetone wash
- S - Sulfate precipitation
- Q - HCl - ether barium chloride scavenge
- R - Rare earth hydroxide scavenge
- Y - Yttrium hydroxide scavenge
- V - 20% HDEHP in toluene
- W - EDTA

Strontium Storage During Ingrowth

- P - Solid
- U - Solution

Yttrium Purification

- H - Yttrium hydroxide precipitation
- L - Fluoride precipitation
- O - Oxalate precipitation
- N_1 - Nitric acid extraction
- (TTA) - Thenoytrifluoracetone extraction
- (TBP) - Tributylphosphate extraction
- (HDEHP) - Di-2-ethylhexyl-o-phosphoric acid extraction

Strontium Yield Determination

- G - Gravimetric
- M - Flame photometric
- JO - Sr^{90} - Y^{90} tracer comparison
- DO - Sr^{85} tracer
- K - Assumed factor

Yttrium Yield Determination

- G - Gravimetric
- M - Flame photometric
- K - Assumed factor

Planchet and Method of Sample Preparation

- SS - Stainless steel
- Al - Aluminum

Pouring -
pouring liquid or slurry directly into planchet

Filtration -
filtering of precipitate onto filter paper which is placed on a disc, covered with mylar, and secured by a ring.

Pipetting -
addition of liquid or slurry directly to planchet by pipette or medicine dropper.

Table VI. DATA AFFECTING STRONTIUM-90 RESULTS

Lab no.	Strontium concentration	Strontium purification	Storage	Yttrium purification	Strontium yield	Yttrium yield	Mean recovery pc/l
9713	C	F	P	(TBP)	G	K	15
2611	C	FC	P	(TBP)	M	K	17
2411	IC	NAFBC	P	(TBP)	G	K	24
7422	C	FBRC	P	(TBP)	M	K	25
8112	C	RC	P	(TBP)	G	K	32
6514-D	EO	---	P	H	---	G	49
7513	C	RC	P	(TBP)R	G	---	50
01	EO	FBO	P	---	past experience	---	55
6512	C	FBC	P	(TBP)	G	K	57
5811	C	RC	P	(TTA)	G	K	67
3731	C	NAFBO	P	---	G	---	70
4933	EO	B	---	---	---	---	71
3316	E	V	U	(HDEHP)	---	K	77
8613b	C	NAFBO	P	---	G	---	79
012	C	N	U	HO	G	G	81
8613a	C	NAFBO	P	---	G	---	82
3416	EC	ONNFB	P	---	G	---	82
05	C	NFBN	P	(TBP)	M	K	83
3611	E	BY	U	HO	---	G	84
02	EC	NFQC	P	HO	G	G	84
08	EN	FBO	P	---	G	---	84
4321	C	NAFBS	P	---	G	---	85
4611	C	CBWS	P	---	G	---	86
6314	EN	NFB	U	HO	DO (2) M (1)	G	87

Table VI. DATA AFFECTING STRONTIUM-90 RESULTS

Planchet	Method of sample preparation	Instrument	Standard	Activity counted	Self-absorption series	Mg/cm^2 sample thickness
50 mm S.S.	Pouring	---	Sr^{90}-Y^{90}	Y^{90}	Yes	---
Al. Milk bottle caps	Pouring	IPC	---	Y^{90}	No	---
50 mm S.S.	Pouring	IPC	---	Y^{90}	No	---
50 mm S.S.	Pipetting	IPC	Tl^{204}	Y^{90}	Yes	---
38 mm S.S.	Pouring	GFEW	Tl^{204}	Y^{90}	Yes	---
25 mm S.S.	Pouring	---	U_3O_8	Sr^{90}	Yes	8.1
50 mm S.S.	Pouring	LBBC GFEW	Tl^{204}	Sr^{90}	No	5.07
25.4 mm S.S.	Pouring	GFEW	EEC	Sr^{90}-Y^{90}	Yes	17.3
51 mm S.S.	Pouring	IPC	Cs^{137}	Y^{90}	No	---
23.8 mm S.S.	Pouring	GFEW	Sr^{90}-Y^{90}	Y^{90}	No	---
50 mm Al.	Pouring	IPC	Tl^{204}	Sr^{90}-Y^{90}	Yes	1.76
31 mm S.S.	Pouring	LBBC GFEW	Sr^{90}-Y^{90}	Sr^{90}	No	---
50 mm S.S.	Pouring	LBBC GFEW	---	Y^{90}	---	---
20 mm Al filter holder /Cu disc.	Filtration	LBBC GFEW	Sr^{90}-Y^{90}	Sr^{90}-Y^{90}	No	---
25 mm S.S.	Filtration	LBBC GFEW	Y^{90}	Y^{90}	No	---
20 mm Al. filter holder /Cu disc.	Filtration	LBBC GFEW	Sr^{90}-Y^{90}	Sr^{90}-Y^{90}	No	---
22 mm plastic	Filtration	GFEW	Sr^{90}-Y^{90}	Sr^{90}-Y^{90}	No	5.04
50.8 mm S.S.	Pipetting	LBBC GFEW	Y^{90}	Y^{90}	No	---
49 mm Al.	Filtration	LBBC GFEW	Y^{90}	Y^{90}	Yes	---
25.4 mm S.S.	Filtration	GMEW	RaD&E	Y^{90}	No	---
31 mm Nickel plate	Filtration	GMEW	Sr^{90}-Y^{90}	Sr^{90}-Y^{90}	No	1.2
---	Pouring	---	---	Sr^{90}	Yes	3.65
25 mm S.S.	Filtration	LBBC GMEW	Sr^{90}	Sr^{90}	Yes	23.65
25 mm S.S.	Filtration	LBBC GMEW	Y^{90}	Y^{90}	No	---

Table VI. DATA AFFECTING STRONTIUM-90 RESULTS

Lab no.	Strontium concentration	Strontium purification	Storage	Yttrium purification	Strontium yield	Yttrium yield	Mean recovery pc/l
8512	C	NAFB	P	HO	M	G	88
4711	C	NFBRC	P	(TTA)	G	K	89
010	E	NFB	U	HO	G	G	91
1811	C	FBR	U	HO	M	G	93
1611	C	NBY	U	HO	G	G	94
5711	C	F	---	---	G		96
5933a	C	NNFBFCN	P	N_1	M	K	96
1311	C	NRC	P	(TBP)	M	K	97
5933b	C	NNFBFCN	P	N_1	M	K	99
2336	EO	OV	U	(HDEHP)	JO	K	100
2811	EC	FC	P	H	G	G	100
7912	C	FBRC	P	HO	G	G	109

Table VI. DATA AFFECTING STRONTIUM-90 RESULTS

Planchet	Method of sample preparation	Instrument	Standard	Activity counted	Self-absorption series	Mg/cm^2 sample thickness
50 mm S. S.	Direct Cent. to Planchet	IPC	Tl^{204}	Y^{90}	Yes	---
30 mm S. S.	Pouring	LBBC GFEW	Y^{90}	Y^{90}	No	---
25 mm semi-cylinder micarta	---	LBBC GMEW	Y^{90}	Y^{90}	No	---
23.4 mm plastic nylon zytel	Filtration	LBBC GFEW	Sr^{90}-Y^{90}	Y^{90}	Yes	---
24 mm S. S.	Filtration	LBBC GFEW	Y^{90}	Y^{90}	Yes	---
49.3 mm S. S.	---	IPC	Sr^{90}-Y^{90}	Sr^{90}	No	8.0
50.8 mm S. S.	Pouring	LBBC GFEW	Sr^{90}	Sr^{90}	Yes	6.50
50.8 mm S. S.	Pouring	IPC	Cs^{137}	Y^{90}	Yes	---
50.8 mm S. S.	Pouring	LBBC GFEW	Y^{90}	Y^{90}	No	---
30 mm S. S.	Pipetting	LBBC GFEW	Sr^{90}-Y^{90}	Y^{90}	No	---
50 mm S. S.	Pouring	LBBC GFEW	Y^{90}	Y^{90}	No	---
18.1 cm Al.	Filtration	GFEW	Sr^{90}-Y^{90}	Y^{90}	No	---

DISCUSSION OF FACTORS AFFECTING STRONTIUM-90 COUNTING DATA

The strontium-90 results seem to have been affected by the:

1 type of counting instrument
2 choice of standard
3 activity counted
4 yttrium-90 separation technique
5 storage of strontium during ingrowth
6 method of strontium yield determination
7 method of yttrium yield determination
8 method of preparing sample for counting

The five lowest results reported were obtained by agencies using tributylphosphate (TBP) solvent extraction for the isolation of yttrium-90. Since all five agencies used the same yttrium-90 separation procedure, it is assumed that a constant error (insufficient extraction of the yttrium-90) was present in each determination. If the yttrium-90 were not completely extracted, then the suggested yield figure for the extraction would be too high, causing the calculated strontium-90 values to be too low. It was decided arbitrarily to reject these five values as outliers, even though the remainder of the results did not necessarily form a normal distribution. These five results, therefore, are not considered in the remainder of the tables.

Type of Counting Instrument

From the results summarized in Table VII, it appears that internal proportional counters are as reliable in determining strontium-90 as gas-flow end-window counters or Geiger Mueller end-window counters at the level of activity present in this sample.

Low level beta counters were used to obtain 15 of the 19 results listed for gas-flow end-window counters. Three of the 5 agencies using Geiger Mueller end-window counters used low background beta counters.

Table VII. SUMMARY OF COUNTING INSTRUMENTS*

	Results	Mean pc/l
Internal Proportional Counters	6	82
Gas-Flow End-Window	18	84
Mean for low background GFEW	15	85
Mean of Others	3	77
Geiger Mueller End-Window	5	86
Low Background GMEW	3	88
Others	2	84

*Two laboratories did not report.

Choice of Standard and Activity Counted

Data in Table VIII relate the calibration standard used to the activity counted. Results appear to be inconclusive, except in the case of yttrium-90. Eleven agencies used yttrium-90 as a calibration standard, counted yttrium-90 activity, and obtained a mean recovery of 89 pc/l.

Table VIII. STANDARD VERSUS ACTIVITY COUNTED*

	Results	Mean pc/l
Activity Counted - Sr^{90}-Y^{90}	6	75
Sr^{90}-Y^{90} standard and Sr^{90}-Y^{90} counted	4	82
Other standards and Sr^{90}-Y^{90} counted	2	62
Activity Counted - Y^{90}	18	88
Y^{90} standard and Y^{90} counted	11	89
Sr^{90}-Y^{90} standard and Y^{90} counted	3	92
Tl^{204} standard and Y^{90} counted	1	88
Other standards and Y^{90} counted	3	79
Activity Counted - Sr^{90}*	7	76
Sr^{90} standard and Sr^{90} counted	2	91
Sr^{90}-Y^{90} standard and Sr^{90} counted	2	89
Other standards and Sr^{90} counted	2	49

*One laboratory did not report standard used.

Yttrium-90 Separation Technique

More reliable results were obtained by precipitation of yttrium carrier as hydroxide, followed by conversion to oxalate precipitate, and then by counting the yttrium oxalate. The nine agencies which followed this procedure obtained a mean recovery value of 90 pc/l over a range of 81-109 pc/l. Three agencies used tributylphosphate extraction to isolate the yttrium-90 activity and obtain a mean recovery of 79 pc/l. Two laboratories used thenoyl-trifluroacetone extraction and recovered a mean value of 78 pc/l, while two laboratories using di-2-ethylhexyl-o-phosphoric acid extraction obtained an average of 88 pc/l. One laboratory used a nitric acid extraction and obtained a value of 99 pc/l, while one laboratory precipitated yttrium as hydroxide and obtained a recovery of 100 pc/l.

Storage of Strontium During Ingrowth*

Twenty-one agencies stored the strontium as a solid and obtained a final mean recovery of 80 pc/l. Eight agencies stored the strontium in liquid form and obtained a mean recovery of 88 pc/l over a range of 77-94 pc/l.

No direct correlation can be drawn here without considering all the variables, except to note that 8 agencies obtained a mean recovery of 88 pc/l, even though the yttrium-90 ingrowth occurred in solution.

Method of Strontium Yield Determination*

Eighteen results from agencies determining strontium carrier yield gravimetrically produced a mean recovery of 82 pc/l. Six results from agencies using flame photometry to determine strontium-carrier yield produced a mean recovery of 93 pc/l. Agencies using other yield methods gave 5 results with a mean of 80 pc/l.

Analysis of the Water-Radioactivity No. 3 sample by the Analytical Reference Service laboratory revealed values of 36 mg/l calcium and 74 mg/l sulfate. Failure to remove the calcium completely could cause slightly lower strontium-90 values for agencies determining strontium yield gravimetrically, since the calcium would appear in the final strontium precipitate and produce a chemical yield on the high side. The sulfate would explain some of the low strontium chemical yields, since strontium sulfate is insoluble and would be a source of strontium carrier loss.

*Two laboratories did not report.

Method of Yttrium Yield Determination

The data indicate that gravimetric determination of yttrium yield produces more reliable results. Ten results by gravimetric yield produced a mean recovery of 91 pc/l. Eight results from solvent extraction procedures produced a mean value of 83 pc/l. The solvent extraction yttrium yields are "assumed" yields, i.e., the recovery of yttrium-90 is determined experimentally by tracer studies and the recovery of tracer is used as the yttrium-yield factor.

Method of Preparing Sample for Counting*

According to the results, the best strontium-90 values were obtained when the sample was prepared for counting by precipitation, filtration, mounting the filter paper, and counting the mounted filter paper. Twelve results by this method produced a mean recovery of 89 pc/l. This may have been due to a more even distribution of solids. Fourteen results obtained from pouring directly onto a planchet gave a mean recovery of 76 pc/l, while two results from pipetting directly onto a planchet produced a mean recovery of 91 pc/l. One laboratory centrifuged the sample directly to the planchet and obtained a value of 88 pc/l.

*Two laboratories did not report

Other Variables

The relation of the other variables (concentration techniques, purification techniques, and sample thickness versus self-absorption) to results were tabulated. No correlation for strontium concentration and purification could be derived as no activity other than strontium-90 yttrium-90 (in equilibrium) was added to the sample. Since data were not available to correlate sample thickness with self-absorption problems, the purification steps and self-absorption problems, although important, were not evaluated extensively. Laboratories should attempt, however, to devise strontium-90 procedures which will insure removal of both stable and radioactive interferences.

CONCLUSION

Evaluation of the 31 results (the 5 lowest mean results were rejected) from 29 agencies who participated in the Water Radioactivity No. 3 study for strontium-90 show trends toward better results rather than being statistically significant.

1 At the level of activity present in this sample, internal proportional counters, gas-flow end-window counters, or Geiger-Mueller end-window counters are satisfactory for determining strontium-90.

2 The standard radionuclide(s) should be the same as the radionuclide(s) counted. This was shown to be true for yttrium-90, but for other standard-activity combinations the results were sketchy.

3 Precipitation of yttrium-90 with yttrium carrier as hydroxide, followed by conversion to oxalate, and then by counting the yttrium oxalate precipitate produced better results than other methods of yttrium-90 separation.

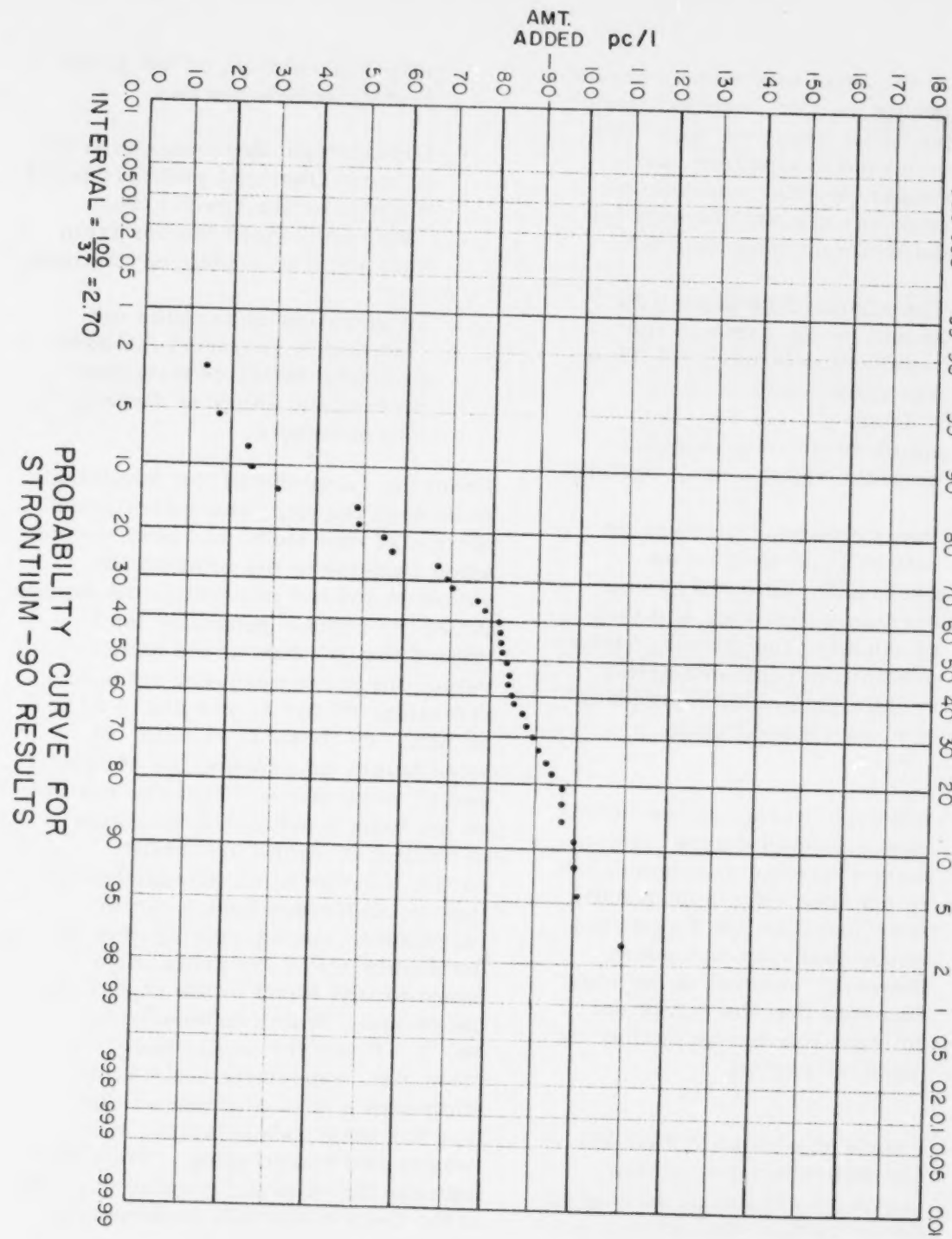
4 Although storage of the strontium as liquid during yttrium ingrowth is not recommended, no adverse effects on results were noted by the 8 agencies which used this procedure. However, several of the eight reported that the strontium solution was acidic during the ingrowth period.

5 Flame photometric methods for determining strontium-carrier yield produced slightly better results than gravimetric methods, due probably to the effect of calcium on the gravimetric determinations.

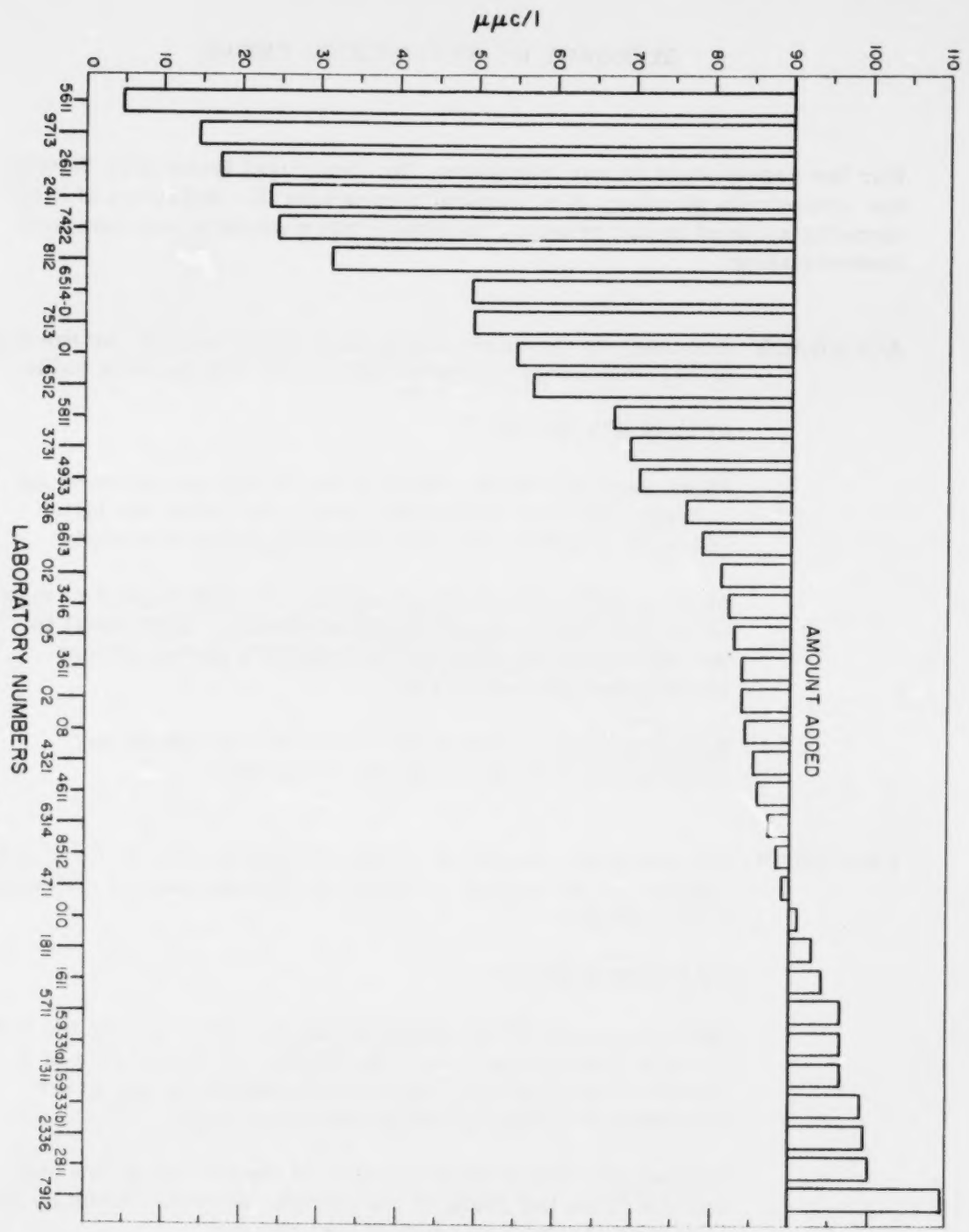
6 Gravimetric determinations for yttrium chemical yield produced slightly better results than "assumed" yield factors from carrier-free solvent extractions.

7 Preparation of samples for counting by filtration methods produced better results than pouring the samples directly into planchets.

From the viewpoint of the Analytical Reference Service, the strontium-90 portion of this study was very encouraging because of the information gathered and the interest in the sample. While the results generally tend toward the low side of the added value, the mean recovery value of strontium-90 for 31 results is 83 pc/l or 92%. Of these 31 results, 21 were below the added value of 90 pc/l and 10 were above. That the results do not form a normal distribution is evident from the probability curve; therefore, no standard deviation or confidence limits can be calculated. An interesting note is the similarity of the probability curve to that found in the report for the sample, Water Radioactivity No. 1. From the public health viewpoint, especially since this study was a first analysis of this type for many laboratories, the results are encouraging. They also indicate the need for greater activity in the field of specific radionuclide analysis.



PROBABILITY CURVE FOR STRONTIUM-90 RESULTS


μμc/l
0
10
20
30
40
50
60
70
80
90
100
110
AMOUNT ADDED
5611
9713
2611
2411
7422
8112
6514-D
7513
01
6512
5811
3731
4933
3316
8613
0112
3416
05
3611
02
08
4321
4611
6314
8512
4711
0110
1811
1611
5711
5933(a)
1311
5933(b)
2336
2811
7912
LABORATORY NUMBERS
WATER-RADIOLOGICAL NO. 3
STRONTIUM-90

GLOSSARY OF STATISTICAL TERMS

For the convenience of our members, the Analytical Reference Service has compiled a glossary of statistical terms with the definition of their meaning as used in our reports, to insure more uniform and complete understanding.

ACCURACY Accuracy is the correctness of a measurement, or the degree of correspondence between the result and the true value.

ACCURACY DATA*

Measurements which relate to the difference between the average test results and the true result when the latter is known or assumed. The following measures apply:

Mean error* - The average difference with regard to sign of the test results from the true results. Also equal to the difference between the average of a series of test results and the true result.

Relative error* - The mean error of a series of test results as a percentage of the true result.

PRECISION Precision is a measure of the reproducibility of the measurements, or the degree to which the measurements correspond to one another.

PRECISION DATA*

Measurements which relate to the variation among the test results themselves, i.e., the scatter or dispersion of a series of test results, without assumption of any prior information. The following measures apply:

Variance* - The sum of squares of deviations of the test results from the mean of the series, after divisions by one less than the total number of test results.

Standard deviation* - The square root of the variance.

Coefficient of variation* -The standard deviation of a series of test results as a percentage of the mean of this series.

Range* - The difference in magnitude between the highest test result and the lowest test result in a series.

Mean* -The sum of a series of test results divided by the number in the series. Arithmetic mean is understood.

Median - The value above and below which an equal number of observations lie.

Percent deviation within laboratory - The average difference between a laboratory's replicate results and the mean, expressed as a percentage of the mean.

Confidence limits - Limits within which the true mean of the series will lie with a given probability.

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* Annual Reviews, Analytical Chemistry, April 1952. pg. 364R.

PROBABILITY EXPLANATION

This section deals with the description and use of normal probability paper. The bell-shaped normal distribution curve can be reduced to a straight line on probability paper; obviously, it is easier to deal with this straight line than with the complicated bell-shaped curve.

Construction of Normal Probability Paper

In an ideal sample, frequencies of the measurements plotted against their magnitudes give a bell-shaped normal distribution curve. This curve is symmetric about its mean, 0, and the percentage of the area lying between any two points on the curve can be found - for example 68.26% of the area under the curve lies between $\pm$ one standard deviation. (Figure 1)

The first step in the construction of normal probability paper is the transformation of the bell-shaped distribution curve to the probability summation curve. This curve gives the summation of the area from left to right under the bell-shaped curve up to any deviation. For example, taking the point, 0, on the x-axis of the summation curve, we read from the y-axis that 50% of the total area lies below this zero value, which is the mean. The summation of area up to a deviation of $-1\ \sigma$ below the mean is 50-34.13 or 15.87%, while the summation of area up to $+1\ \sigma$ above the mean is 50 + 34.13 or 84.13%. Similarly, other transformations can be made, forming a complete, smooth ogee or s-shaped curve. (Figure 2)

The next step is to reduce the probability summation curve to a straight line. This is done by projecting the points on the ogee curve vertically to the linear x-axis scale and by writing the corresponding percentage opposite each point. For example, project point a to a' and write its probability summation (15.87%); project b to b' and write 85.13%, etc. Such a scale, with the percentages shown, constitutes the x-axis of normal probability paper.

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Plotting on Normal Probability Paper

Since the probability summation is the cumulative area from left to right, it represents probability of a measurement "equal to or less than" a given value. Arranging the data in ascending order of magnitude automatically places them in the order of their position on the probability summation scale. This arrangement permits ready determination of the probability not exceeding a certain magnitude of measurement.

In the development of the probability paper, many difficulties were encountered in choosing a formula for plotting the position of the measurements on the probability summation scale (or x-axis), but the problem was solved in the following way. Ideally, the plotting position for the mean of any series, regardless of the number of values, is at 50% - half of the values above and half below. If the mean is considered as part of the series, the number of plotting positions becomes n + 1. Thus the x-axis, which represents 100%, is divided into n + 1 intervals. To plot the third point, for example, multiply $\frac{1}{n+1}$ by 3, or $3\left(\frac{1}{n+1}\right)$. Therefore, the formula for the plotting interval is $\frac{m}{n+1}$ where m equals the serial number of the measurements arranged in ascending order of magnitude, and n equals the total number of measured values to be plotted. Multiplication of the resulting value by 100 converts the ratio to a percentage.

In summary, the procedure for plotting data on normal probability paper is as follows:

1. Array data in order of ascending magnitude.

2. Calculate the plotting position of each value by the expression $\frac{m(100)}{n+1}$ which gives the ratio as a percentage. This point designates the percentage of the values that are equal to or less than the plotted value.

3. The y-axis is graduated linearly from the lowest to the highest reported value, while the x-axis is graduated according to the probability scale. Place the first (lowest) value above the calculated plotting interval for m=1 on the x-axis and at the appropriate value on the y-axis (magnitude). Plot the next value above the plotting interval for m=2 on the x-axis and at the appropriate value on the y-axis. Plot the remaining values in a similar manner.

INTERPRETATION

If a straight line develops in the plotting, the data have a normal distribution; that is, in accordance with the theory of probability, this is the expected distribution of results.

If a straight line does not develop in the plotting, a change in the conditions affecting the observed measurements is suspected. It may mean for example, that the same characteristic has not been measured under the same conditions.

Sometimes the great majority of the data approximate a straight line, but on the ends some results will be either extremely high or low. Just as one of these erratic results is far removed from the others on the bell-shaped normal curve, so it is far removed from the others on the straight-line curve. When this happens these erratic results are presented in the published report on the probability curve, but the statistics are based on only the normal segment of the distribution.

Example for Use

One application of these instructions for the construction of the probability curve is given below using the data from the gross beta analyses.

1. The data used are the average values reported by each laboratory.

2. With a total of fifty-three results to be plotted, the plotting interval equals 100/53 + 1 or 100/54, which equals 1.85.

3. The y-axis is graduated to include as many of the results as possible; in this case all of the results could be plotted. The plotting intervals are marked on the x-axis as 1.85, 3.70, 5.55, . . . 94.35, 96.20, 98.05.

4. Plot the values.

5. Draw the line of best fit through the points.

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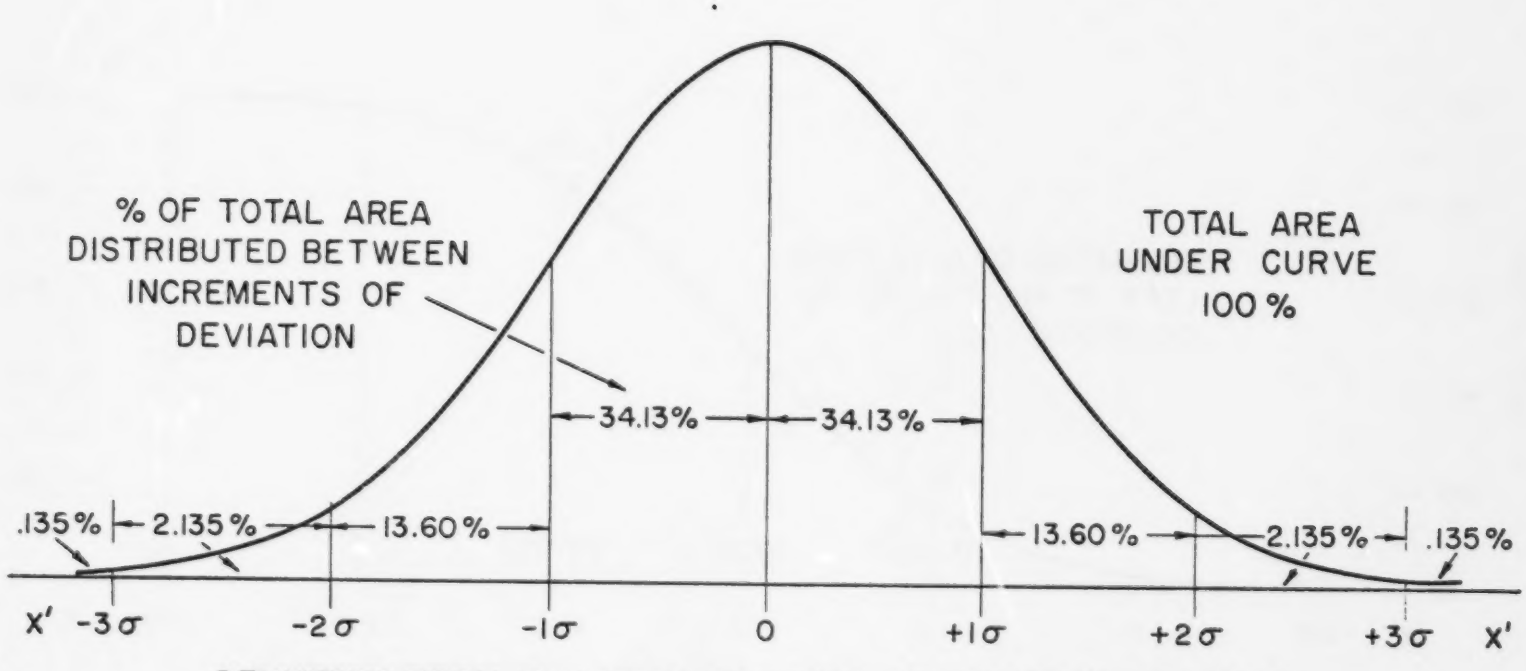
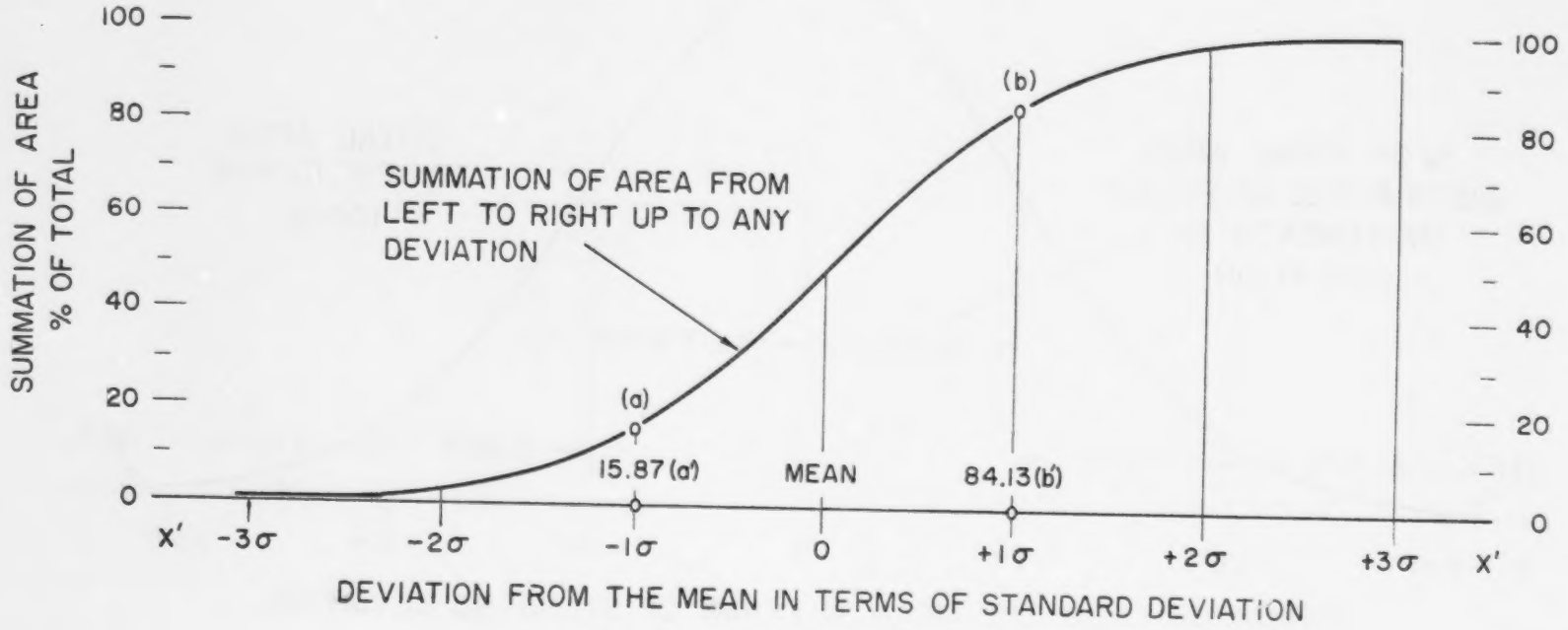


THE BELL-SHAPED DISTRIBUTION CURVE

Figure 1.



THE OGEE SUMMATION CURVE

Figure 2.

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